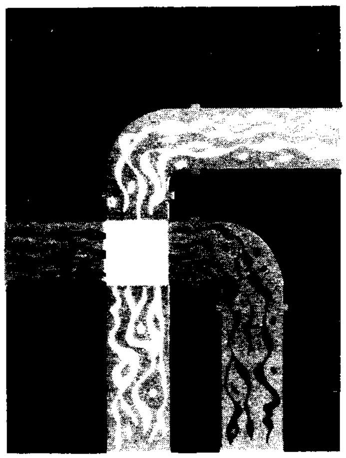
Chapter Three

Theory of Backflow and Backsiphonage



A *cross-connection* [1] is the link or channel connecting a source of pollution with a potable water supply. The polluting substance, in most cases a liquid, tends to enter the potable supply if the net force acting upon the liquid acts in the direction of the potable supply. *Two* factors are therefore essential for backflow. *First*, there must be a *link* between the two systems. *Second*, the resultant *force* must be *toward* the potable supply.

An understanding of the principles of backflow and back-siphonage requires an understanding of the terms frequently used in their discussion. *Force*, unless completely resisted, will produce motion. *Weight* is a type of force resulting from the earth's gravitational attraction. *Pressure (P)* is a force-per-unit area, such as pounds per square inch (psi). *Atmospheric pressure* is the pressure exerted by the weight of the atmosphere above the earth.

Pressure may be referred to using an absolute scale, pounds per square inch absolute (psia), or gage scale, pounds per square inch gage (psig). Absolute pressure and gage pressure are related. Absolute pressure is equal to the gage pressure plus the atmospheric pressure. At sea level the atmospheric pressure is 14.7 psia. Thus,

P absolute = P gage + 14.7 psi
or
P gage = P absolute - 14.7 psi

In essence then, absolute pressure is the total pressure. Gage pressure is simply the pressure read on a gage. If there is no pressure on the gage other than atmospheric, the gage would read zero. Then the absolute pressure would be equal to 14.7 psi which is the atmospheric pressure.

The term *vacuum* indicates that the absolute pressure is less than the atmospheric pressure and that the gage pressure is negative. A complete or total vacuum would mean a pressure of 0 psia or -14.7 psig. Since it is impossible to produce a total vacuum, the term *vacuum*, as used in the text, will mean all degrees of partial vacuum. In a partial vacuum, the pressure would range from slightly less than 14.7 psia (0 psig) to slightly greater than 0 psia (-14.7 psig).

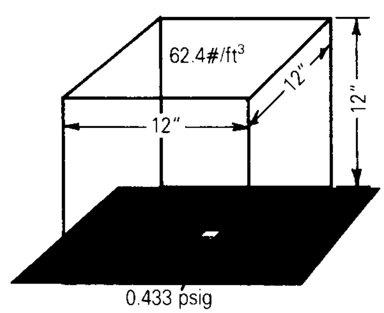
Backsiphonage[1] results in fluid flow in an undesirable or reverse direction. It is caused by atmospheric pressure exerted on a pollutant liquid forcing it toward a potable water supply system that is under a vacuum. *Backflow*, although literally meaning any type of reversed flow, refers to the flow produced by the differential pressure existing between two systems both of which are at pressures greater than atmospheric.

Water Pressure

For an understanding of the nature of pressure and its relationship to water depth, consider the pressure exerted on the base of a cubic foot of water at sea level. (See Fig. 1.) The average weight of a cubic foot of water is 62.4 pounds per square foot gage. The base may be subdivided into 144-square inches with each subdivision being subjected to a pressure of 0.433 psig.

Suppose another cubic foot of water were placed directly on top of the first (See Fig. 2). The pressure on the top surface of the first cube which was originally atmospheric, or 0 psig, would now be 0.433 psig as a result of the superimposed cubic foot of water. The pressure of the base of the first cube would also be inreased by the same amount of 0.866 psig, or two times the original pressure.

FIGURE 1.
Pressure exerted by 1 foot of water at sea level.

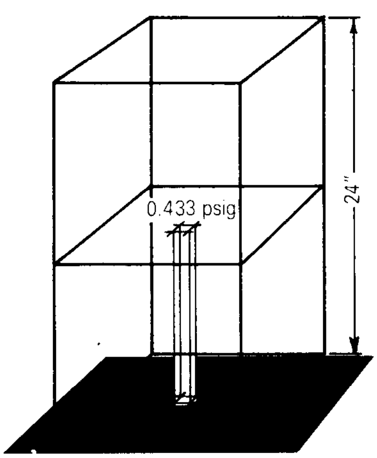


[1] See formal definition in the glossary of the appendix.

If this process were repeated with a third cubic foot of water, the pressures at the base of each cube would be 1,299 psig, 0.866 psig, and 0.433 psig, respectively. It is evident that pressure varies with depth below a free water surface[1]. in general each foot of elevation change, within a liquid, changes the pressure by an amount equal to the weight-per-unit area of 1 foot of the liquid. The rate of increase for water is 0.433 psi per foot of depth.

Frequently water pressure is referred to using the terms "pressure head" or just "head," and is expressed in units of feet of water. One foot of head would be equivalent to the pressure produced at the base of a column of water 1 foot in depth. One foot of head or 1 foot of water is equal to 0.433 psig. One hundred feet of head are equal to 43.3 psig.

FIGURE 2.
Pressure exerted by 2 feet of water at sea level.

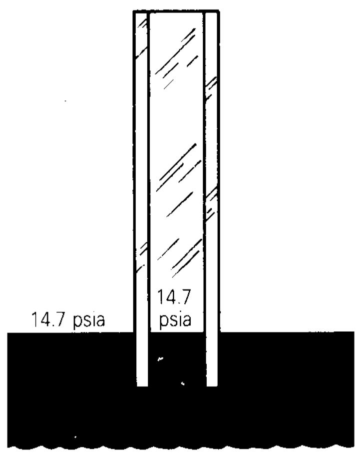


[1]See formal definition in the glossary of the appendix.

Siphon Theory

Figure 3 depicts the atmospheric pressure on a water surface at sea level. An open tube is inserted vertically into the water; atmospheric pressure, which is 14.7 psia, acts equally on the surface of the water within the tube and on the outside of the tube.

FIGURE 3.
Pressure on the free surface of a liquid at sea level.



If, as shown in Figure 4, the tube is slightly capped and a vacuum pump is used to evacuate all the air from the sealed tube, a vacuum with a pressure of 0 psia is created within the tube. Because the pressure at any point in a static fluid is dependent upon the height of that point above a reference line, such as sea level, it follows that the pressure within the tube at sea level must still be 14.7 psia. This is equivalent to the pressure at the base of a column of water 33.9 feet high and with the column open at the base, water would rise to fill the column to a depth of 33.9 feet. In other words, the weight of the atmosphere at sea level exactly balances the weight of a column of water 33.9 feet in height. The absolute pressure within the column of water in Figure 4 at a height of 11.5 feet is equal to 9.7 psia. This is a partial vacuum with an equivalent gage pressure of -5.0 psig.

As a practical example, assume the water pressure at a closed faucet on the top of a 100-foot high building to be 20 psig; the pressure on the ground floor would then be 63.3 psig. If the pressure at the ground were to drop suddenly due to a heavy fire demand in the area to 33.3 psig, the pressure at the top would be reduced to -10 psig. If the building water system were airtight, the water would remain at the level of the faucet because of the partial vacuum created by the drop in pressure. If the faucet were opened, however, the vacuum would be broken and the water level would drop to a height of 77 feet above the ground. Thus, the atmosphere was supporting a column of water 23 feet high.

Figure 4.
Effect of evacuating air from a column.

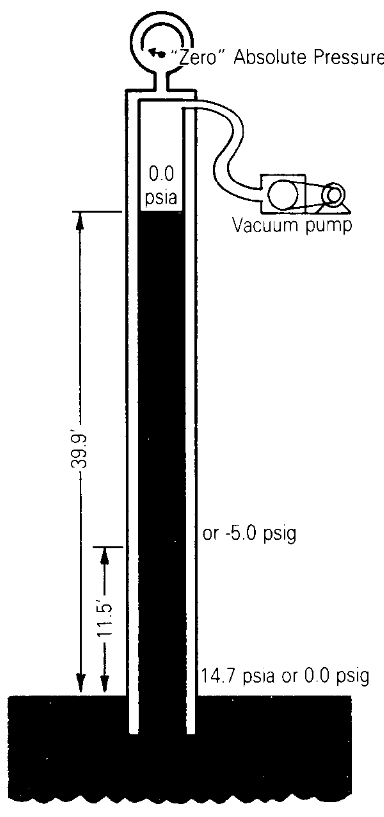
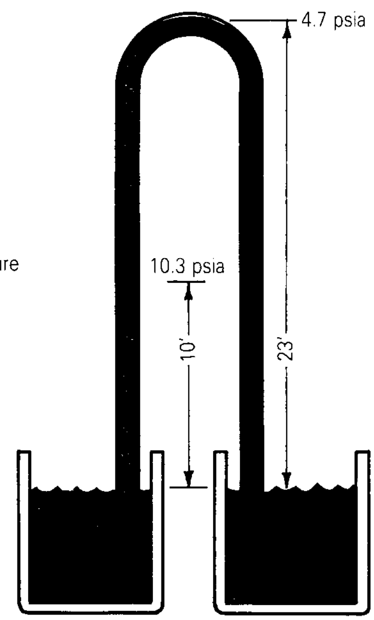


Figure 5 is a diagram of an inverted U-tube that has been filled with water and placed in two open containers at sea level.

If the open containers are placed so that the liquid levels in each container are at the same height, a static state will exist; and the pressure at any specified level in either leg of the U-tube will be the same.

FIGURE 5.
Pressure relationships in a continuous fluid system at the same elevation.



The equilibrium condition is altered by raising one of the containers so that the liquid level in one container is 5 feet above the level of the other. (See Fig. 6.) Since both containers are open to the atmosphere, the pressure on the liquid surfaces in each container will remain at 14.7 psia.

If it is assumed that a static state exists, momentarily, within the system shown in Figure 6, the pressure in the left tube at any height above the free surface in the left container can be calculated. The pressure at the corresponding level in the right tube above the free surface in the right container may also be calculated.

As shown in Figure 6, the pressure at all levels in the left tube would be less than at corresponding levels in the right tube. In this case, a static condition cannot exist because fluid will flow from the higher pressure to the lower pressure; the flow would be from the right tank to the left tank. This arrangement will be recognized as a siphon. The crest of a siphon cannot be higher than 33.9 feet above the upper liquid level, since atmosphere cannot support a column of water greater in height than 33.9 feet.

FIGURE 6.
Pressure relationships in a continuous fluid system at different elevations.

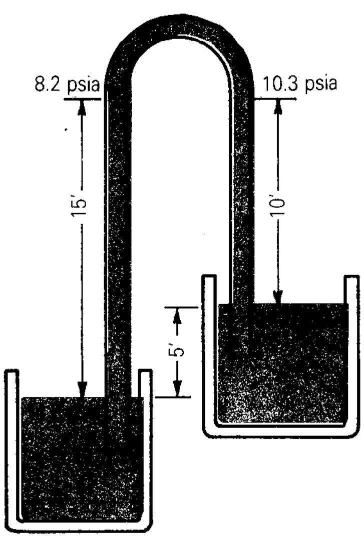


FIGURE 7.
Backsiphonage in a plumbing system.

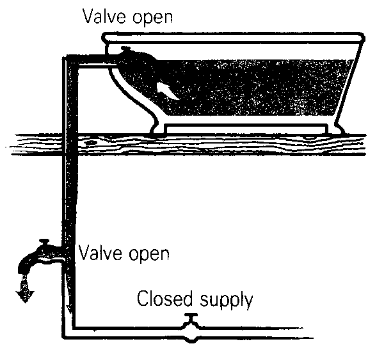


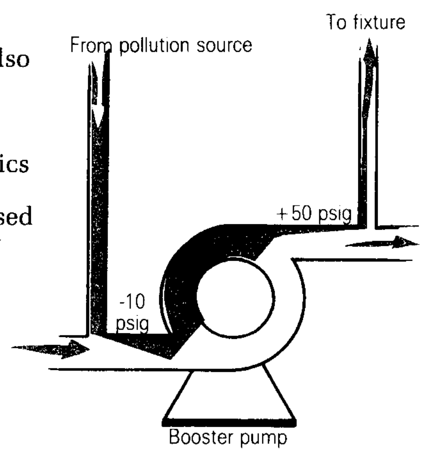
Figure 7 illustrates how this siphon principle can be hazardous in a plumbing system. If the supply valve is closed, the pressure in the line supplying the faucet is less than the pressure in the supply line to the bathtub. Flow will occur, therefore, through siphonage, from the bathtub to the open faucet.

The siphon actions cited have been produced by reduced pressures resulting from a difference in the water levels at two separated points within continuous fluid system.

Reduced pressure may also be created within a fluid system as a result of fluid motion. One of the basic principles of fluid mechanics is the principle of conservation of energy. Based upon this principle, it may be shown that as a fluid accelerates, as shown in Figure 8, the pressure is reduced. As water flows through a constriction such as a converging section of pipe, the velocity of the water increases; as a result, the pressure is reduced. Under such conditions, negative pressures may be developed in a pipe. The simple aspirator is based upon this principle. If this point of reduced pressure is linked to a source of pollution, backsiphonage of the pollutant can occur.

FIGURE 8.
Negative pressure created by constricted flow.

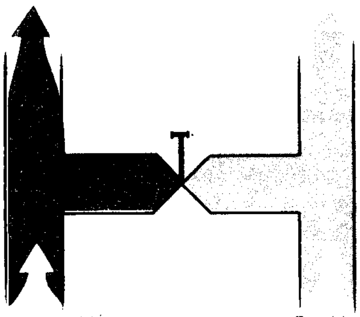
FIGURE 9.
Dynamically reduced pipe pressures.



One of the common occurences of dynamically reduced pipe pressures is found on the suction side of a pump. In many cases similar to the one illustrated in Figure 9, the line supplying the booster pump is undersized or does not have sufficient pressure to deliver water at the rate at which the pump normally operates. The rate of flow in the pipe may be increased by a further reduction in pressure at the pump intake. This often results in the creation of negative pressure at the pump intake. This often results in the creation of negative pressure. This negative pressure may become low enough in some cases to cause vaporization of the water in the line. Actually, in the illustration shown, flow from the source of pollution would occur when pressure on the suction side of the pump is less than pressure of the pollution source; but this is *backflow*, which will be discussed below.

The preceding discussion has described some of the means by which negative pressures may be created and which frequently occur to produce backsiphonage. In addition to the negative pressure or reversed force necessary to cause backsiphonage and backflow, there must also be the cross-connection or connecting link between the potable water supply and the source of pollution. Two basic types of connections may be created in piping systems. These are the *solid pipe* with valved connection and the *submerged inlet*.

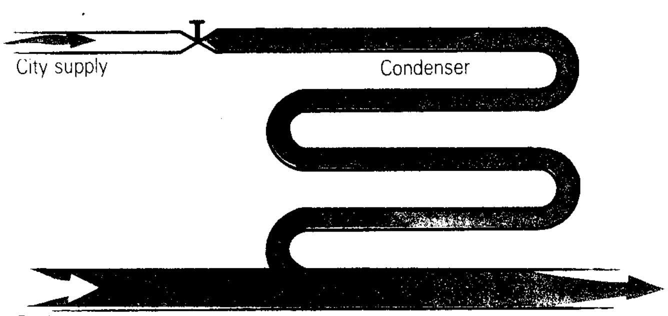
FIGURE 10.
Valved connection between potable water and nonpotable fluid.



Figures 10 and 11 illustrate solid connections. This type of connection is often installed where it is necessary to supply an auxiliary piping system from the potable source. It is a direct connection of one pipe to another pipe or receptacle.

Solid pipe connections are often made to continuous or intermittent waste lines where it is assumed that the flow will be in one direction only. An example of this would be used cooling water from a water jacket or condenser as shown in Figure 11. This type of connection is usually detectable but creating a concern on the part of the installer about the possibility of reversed flow is often more difficult. Upon questioning, however, many installers will agree that the solid connection was made because the sewer is occasionally subjected to backpressure.

FIGURE 11.
Valved connection between potable water and sanitary sewer.



Submerged inlets are found on many common plumbing fixtures and are sometimes necessary features of the fixtures if they are to function properly. Examples of this type of design are siphon-jet urinals or water closets, flushing rim slop sinks, and dental cuspidors. Oldstyle bathtubs and lavatories had supply inlets below the flood level rims, but modern sanitary design has minimized or eliminated this hazard in new fixtures. Chemical and industrial process vats sometimes have submerged inlets where the water pressure is used as an aid in diffusion, dispersion and agitation of the vat contents. Even though the supply pipe may come from the floor above the vat, backsiphonage can occur as it has been shown that the siphon action can raise a liquid such as water almost 34 feet. Some submerged inlets difficult to control are those which are not apparent until a significant change in water level occurs or where a supply may be conveniently extended below the liquid surface by means of a hose or auxiliary piping. A submerged inlet may be created in numerous ways, and its detection in some of these subtle forms may be difficult.

The illustrations included in part B of the appendix are intended to describe typical examples of backsiphonage, showing in each case the nature of the link or cross-connection, and the cause of the negative pressure.

Backflow

Backflow[1], as described in this manual, refers to reversed flow due to backpressure other than siphonic action. Any interconnected fluid systems in which the pressure of one exceeds the pressure of the other may have flow from one to the other as a result of the pressure differential. The flow will occur from the zone of higher pressure to the zone of lower pressure. This type of backflow is of concern in buildings where two or more piping systems are maintained. The potable water supply is usually under pressure directly from the city water main. Occasionally, a booster pump is used. The auxiliary system is often pressurized by a centrifical pump, although backpressure may be caused by gas or steam pressure from a boiler. A reversal in differential pressure may occur when pressure in the potable system drops, for some reason, to a pressure lower than that in the system to which the potable water is connected.

The most positive method of avoiding this type of backflow is the total or complete separation of the two systems. Other methods used involve the installation of mechanical devices. All methods require routine inspection and maintenance.

Dual piping systems are often installed for extra protection in the event of an emergency or possible mechanical failure of one of the systems. Fire protection systems are an example. Another example is the use of dual water connections to boilers. These installations are sometimes interconnected, thus creating a health hazard.

The illustrations in part C of the appendix depict installations where backflow under pressure can occur, describing the cross-connection and the cause of the reversed flow.

[1] See formal definition in the glossary of the appendix.